(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 869 330 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
07.10.1998 Bulletin 1998/41

(51) Int Cl.6: G01B 11/06

(21) Application number: 98302090.0

(22) Date of filing: 19.03.1998

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 02.04.1997 GB 9706656

(71) Applicant: Assembly Technology & Test Limited
London EC3A 7NJ (GB)

(72) Inventor: Whitehead, Mark
Northwich, Cheshire, CW9 8FB (GB)

(74) Representative: Crouch, David John et al
Bromhead & Co.
19 Buckingham Street
London WC2N 6EF (GB)

(54) Apparatus for testing tyre tread depth

(57) An apparatus for determining the depth of a tyre tread includes a radiation source for illuminating the tread of a tyre, the direction of the illumination being non-normal with respect to the local surface of a portion of a tyre under inspection, at least one detector responsive to radiation reflected from the tyre, and a data processor responsive to the at least one detector for calculating the tread depth. In one embodiment, differences in displacement between radiation reflected from the top surface of a tread and radiation reflected from the bottom surface of a tread are measured to determine tread depth. In a second embodiment, the shadow cast by the top surface of the tread over the bottom surface of the tread is measured to determine tread depth. A third embodiment employs a sheet of radiation with varying wavelength to determine the tread depth.

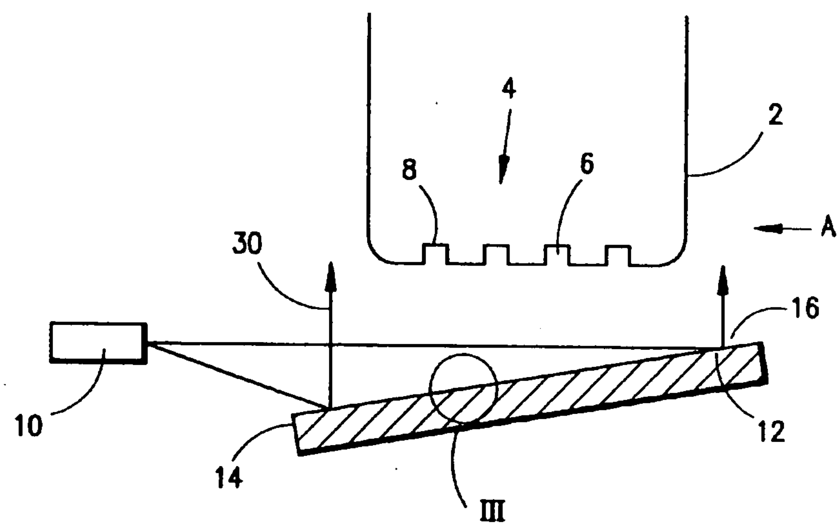

FIG. 1

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Description

FIELD OF THE INVENTION

The present invention relates to an apparatus for testing the depth of tread on a tyre. Such an apparatus is suitable for inclusion in a rolling road, such as is used for brake testing, or it may be provided as a hand held or ramp mounted unit for performing road side testing or diagnostic testing of tyres.

BACKGROUND OF THE INVENTION

Legislation in the UK requires that a tyre should have at least 1.6 mm of tread over 75% of it's road surface contact area for a car tyre. Different limits apply for the other types of vehicles. Hitherto, the estimation of tread depth, and more particularly, whether this depth is maintained across the required width of the road contact area, has been performed mainly by manual inspection.

WO 96/10727 discloses a tyre scanning apparatus in which a light source and a photodetector are mounted in a carriage which is driven back and forth along a scan path by a motor and drive belt. The use of a mechanical scanning system of this type may lead to an unacceptable failure rate of the system.

SUMMARY OF THE INVENTION

According to the present invention, there is provided a tyre tread inspection apparatus, comprising a radiation source for illumination the tread of a tyre, the direction of the illumination being inclined with respect to the local surface of a portion of a tyre under inspection, at least one detector responsive to radiation reflected from the tyre, and a data processor responsive to the at least one detector for indicating the acceptability of the tyre.

It is thus possible to provide an automated tyre inspection apparatus. The use of non-normal illumination enables the detector to be situated remote from the surface of the tyre and thereby simplifies the scanning mechanism.

Preferably the radiation is light. As used herein, light includes electromagnetic radiation falling within the ultraviolet, visible and infra-red portions of the spectrum. Advantageously the at least one detector is a photodetector.

Advantageously a light spot may be scanned across the surface of the tyre. The scan path may be direct from one side of the tyre to the other. Thus the light spot may traverse a path which is substantially parallel with the axis of rotation of the tyre.

Preferably the portion of the tyre under inspection is not in contact with a surface. Thus the portion of tread under inspection is not under a compressive load during the test.

Preferably the tread inspection apparatus does not include any moving parts in the scanning system. The provision of a system which does not include moving parts can be expected to greatly improve the mean time between failure of the apparatus. Alternatively a simple mechanical scanning means, such as a rotating mirror may be utilised.

During an inspection, there may be relative motion between the inspection apparatus and the tyre. This may be because the tyre is being rotated on a testbed, such as a rolling road, or because the inspection apparatus or at least a sensor head thereof is being moved around the periphery of a tyre, for example during a road side inspection. A consequence of the relative motion is that the light beam no longer traverses the shortest distance between the sides of the tyre. However, this does not effect the accuracy or validity of the test, but may require to be compensated for if the data processor performs tyre type identification on the basis of the tread pattern.

The effects of relative motion may be corrected by skewing the scan path such that the skew and the tyre tread displacement due to rotation of the tyre during a scan substantially cancel one another. Alternatively, the data processor may be arranged to manipulate the received data in order to remove the effects of the relative motion. Such manipulation may involve merging or interpolating data from adjacent scans.

The light spot may be scanned by a rotating mirror, a reciprocating mirror or by reciprocal displacement of the light source.

Preferably the light source is a laser. Other collimated light sources may also be used.

Alternatively a sheet of light may be used to illuminate the tyre. Such a sheet of light may be generated by rapid and repeated scanning of a light spot across the surface. Alternatively, the sheet of light may be formed by distorting a collimated beam along one direction. This may be performed by passing the beam through a cylindrical lens. Alternatively commercially available laser line devices may be used to generate the sheet of light. As a further alternative an elongate light source, such as a fluorescent tube, may be used with a collimating arrangement.

Use of a beam inclined with respect to the local (i. e. scanned) surface of a tyre means that the position of the light when it reflects from the tyre is a function of the position of the surface with respect to the light source. Since a treaded tyre has an undulating surface, the position of the reflected light should vary in accordance with the depth of the tread and the profile of the tyre. More specifically, the light beam will be displaced perpendicularly to the scan direction (or longitudinal axis of the sheet of light) in accordance with the depth of the tyre tread.

Advantageously the light from the light source is directed towards the surface of the tyre by a light guide arrangement.

Such an arrangement may include a faceted mirror.

A faceted mirror may have a sawtooth profile. This enables the mirror to be arranged at only a relatively shallow angle to the surface of the tyre whilst still allowing the light to be directed at the tyre at a much steeper angle thereby enabling a physically compact test head to be used. Light reflected from the tyre is collected by an imaging system and returned to the one or more photodetectors.

Where the light beam is scanned across the tyre, the reflected light may be directed onto a one dimensional array of photodetectors in order to form a measurement of the position of the point of reflection. Alternatively a single detector may be used in conjunction with an optical scanning system such that the detector inspects small areas of the tyre surface in a sequential manner. As a further alternative a two dimensional array of detectors (i.e. camera) may be used to record the reflected light pattern.

Preferably the reflected light is returned to the or each photodetector by a further faceted mirror. The, two faceted mirrors may be inclined with respect to one another.

As an alternative to the use of faceted mirrors, transparent prisms utilising total internal reflection may be used to obtain the same optical action. As a further alternative a diffraction element may be used to simultaneously form the reflection and also to focus the image directly on to the photodetector or camera.

The optical system may be arranged within a hand held unit. The hand held unit may have an open slit or a window which, in use, faces towards the tyre, and rollers or other guide arrangements such that the hand held unit can be rotated around the surface of the tyre with the slit or window facing towards the tyre in order to assess the tread.

Alternatively the light source and imaging system may be built into a larger static test apparatus. In such an arrangement, it is not necessary for the light source and the imaging system to be adjacent one another. In an embodiment of a rolling road incorporating such a system, the light source and the detector are separated from one another by approximately half a metre.

The tyre tread detector may be capable of analysing treads on axles carrying two or more wheels, such as is the case with heavy goods vehicles. Thus the scan may extend along a line of 1.1 metres or more. Embodiments of the system are able to scan a tyre width of 800 mm with the lateral resolution better than 0.5 mm and typically a lateral resolution of 0.25 mm. Furthermore the system can measure the tread depth with a resolution of 0.1 mm or better. The system may be arranged to scan the tyre surface at 10 mm intervals or less, although it is preferred that the scan should occur every 2 mm around the circumference of the tyre. For a tyre rotating at 722 mm a second this results in making 72 scans per second at 10 mm intervals and 361 scans per second at 2 mm intervals, respectively.

Advantageously the at least one photodetector is a charged coupled device (CCD) camera. Such cameras allow faster data rates than traditional video cameras. Suitable camera configurations include 256 x 256 pixel arrays, 2048 x 2048 pixel arrays (or higher), or line arrays such as 1 x 256, 1 x 2048 or higher.

An instantaneous scan across the tyre can be performed when a camera is used to view the tyre tread. Thus the camera is particularly suited for use in those embodiments employing a continuous sheet of light rather than a scanning spot.

The output of the camera may be sent to a frame grabber for temporary storage before transfer to the data processor. Or data processing may be carried out on the chip itself.

In an alternative tyre inspection apparatus constituting a further embodiment of the present invention, at least one light source is used to obliquely illuminate the tyre, in such a way that shadows are formed within the recessed portions of the tread pattern. Advantageously a second light source is also provided for illuminating the tyre from a different direction. The first and second light sources may be arranged to operate in an alternating sequence and may be arranged such that the light they produce comes from opposing directions thus, for example, the inspection apparatus may illuminate the tyre in an alternating sequence from either side of the plane of the tyre. Those portions of the tyre which are illuminated will reflect a greater intensity of light that those portions at the bottom of the treads which are in a shadowed region. By comparing the reflected light patterns when the tyre is illuminated from each side it is possible to work out the depth of the tread and also to allow for and identify asymmetric wear where that may have occurred.

In a further alternative type of inspection apparatus, the light used to illuminate the tyre has a spatially varying wavelength distribution. That is, in respect of visible light, it has a spatially varying colour distribution. Such a distribution may be obtained by passing light from a broadband light source through a diffraction grating or prism.

The spatially varying light typically emerges from the diffraction grating or prism as a broad beam of light where the wavelength/colour changes across the beam. The beam is directed onto the surface of the tyre under test and a selected region of tyre is inspected so as to analyse the wavelength/polour of light reflected from the selected region. The wavelength/colour of the reflected light is a function of the position of the surface reflecting the light and hence conveys information concerning the tread depth.

The light source may be continually illuminated, or may be pulsed. Pulsed operation may be advantageous as it may allow for ambient light to be measured and then compensated for in the measurement process.

According to a second aspect of the present invention, there is provided an optical inspection arrangement comprising a light source for obliquely illuminating a por-

tion of a tyre and at least one image receiving arrangement for receiving light reflected from the tyre.

Preferably the image receiving arrangement is at least one photodetector for supplying a signal to a data processor. Alternatively the image receiving arrangement may be a screen for enabling the image to be viewed.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will further be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 schematically represents a first preferred embodiment of an apparatus for inspection of a tyre tread according to the present invention;

Figure 2 is a perspective schematic view of the optical path to and from a tyre under test for the apparatus of Figure 1;

Figure 3 is a cross sectional view of a portion of a faceted mirror shown in circle III of Figure 1;

Figure 4 schematically illustrates the optical paths for light reflected from the surface of the tyre and for light reflected from the bottom of the tread pattern with the apparatus of Figure 1;

Figure 5 shows the difference in optical paths at the tyre surface with the apparatus of Figure 1 in greater detail;

Figure 6 schematically illustrates a trace produced from a single line scan across a tyre by the apparatus of Figure 1;

Figure 7 is a perspective diagram of an imaging arrangement used in a second preferred embodiment of an apparatus for inspection of a tyre tread according to the present invention;

Figures 8 and 9 schematically illustrate an imaging arrangement of a third preferred embodiment of an apparatus for inspection of a tyre tread according to the present invention;

Figure 10 is a perspective diagram of a sensor head used as part the apparatus of Figures 8 and 9;

Figure 11 is a perspective diagram of a fourth preferred embodiment of an apparatus for inspection of a tyre tread according to the present invention in the form of hand held apparatus;

Figure 12 schematically illustrates a fifth preferred embodiment of an apparatus for inspection of a tyre tread according to the present invention incorporated within a rolling road;

Figure 13 schematically represents a sixth preferred embodiment of an apparatus for inspection of a tyre tread according to the present invention;

DETAILED DESCRIPTION OF THE EMBODIMENTS

As shown in figure 1, a tyre 2 is provided with a treaded road contacting portion 4. The tread serves to increase the grip between the tyre 2 and a road surface (not shown), and consists of a pattern of grooves 6 cut into the surface of the tyre 2. The depth of those grooves 6 will be referred to herein as the tread depth and the radially innermost portion 8 of the grooves 6 will be referred to the bottom of the tread.

The inspection apparatus comprises a light source 10 and a reflector 12. The light source 10 produces a sheet of light 30, i.e. it produces a line of illumination along the surface of the tyre 2.

In one embodiment of the invention, the line of light is produced by an elongate light source and a suitable collimating system. However, the preferred means for producing the elongate line are a scanned laser spot, produced, for example by a solid state laser in combination with a rotating or reciprocating mirror in order to scan the spot along a line (such devices are well known and need not be described here), or a laser line generator. An example of a commercially available laser line generator is a line generator from Vector Technology Limited, which generates a line with a total fan angle of 106°. This gives a total line width of 1100 mm at a distance of 414.5 mm from the source. However, due to possible aberration effects, it is prudent to use a spacing greater than this minimum distance. However, it is possible to use a plurality of these devices in combination to produce a longer line or to reduce the distance between the source and the tyre 2. Light from the light source 10 extends (or is scanned between) positions 14 and 16 on the surface of the reflector 12. The reflector 12 may be a faceted mirror. The reflector 12 reflects the light towards the tyre 2 in such a manner that, when viewed in the plane of figure 1, the light is directed radially inwards towards the surface of the tyre 2.

Figure 2 illustrates the relative positions of the optical paths to and from the tyre 2 in greater detail. The tyre 2 has an axis of rotation represented by a chain line 17. A second chain line 18 represents the radial path between the axis of rotation and the portion 19 of the tyre 2 which is being inspected. Light 30 directed towards the surface of the tyre 2 is perpendicular to but not coincident with the axis of rotation 17 and is inclined with respect to a plane containing lines 17 and 18. As shown in Figure 2, the light 30 incident on the tyre 2 is above the plane and inclined with respect to the plane by an angle θ. Light 23 specularly reflected from the tyre 2 lies below the plane and is inclined thereto by θ.

Figure 3 illustrates the section of the faceted mirror 12 in circle III of Figure 1 in greater detail. The faceted mirror 12 comprises a series of triangular sections 20 each having a surface 22. The surface 22 is inclined such that it reflects light from the light source 10 towards the tyre 2 such that the tyre 2 is illuminated as shown in Figure 2.

Figure 4 represents the view along the direction of arrow A in figure 1. As shown in figure 4, the light 30 from the light source 10 and mirror (not shown) forms a plane of light which is inclined with respect to the surface normal 32 of the portion of the surface under inspection. Light which is reflected from the bottom of the tread 8 (as represented by the chain dot line in figure 4) travels slightly further than light reflected from the surface of the tyre 2. Light specularly reflected from the tyre 2 is directed towards a photodetector 34. In the arrangement shown in figure 4, light 36 reflected from the surface of the tyre 2 is physically displaced from light 38 reflected from the bottom 8 of the tread. The displacement between the reflected light 36 and 38 is a function of the depth of the tyre tread. This is shown in greater detail in Figure 5. As shown in Figure 5, the light beams become displaced by a distance L where $L = 2D\cos\theta\tan\theta$, where D is the depth of the tyre tread and θ is the angle of incidence. The photodetector 34 may be a linear array of charged coupled devices which, when used in association with a scanning laser spot, can be used to build up an image of the tread depth across a scan line. However, if the light source produces a line of laser light continually across the tyre 2, then the detector may be a camera which directly images the reflected light pattern. Such a reflected light pattern is schematically illustrated in figure 6. The portions of the line 38 represent the position of the bottom of the tread, whereas the portions 36 represent the position of the surface of the tyre 2. The distance L between the lines 36 and 38 is indicative of the depth of the tyre tread. However, the optical inspection technique in fact provides a surface profile across the width of the tyre 2 and can be used to make a more complex assessment of tyre conditions, such as an analysis of uneven wear across the tyre 2.

Figure 7 illustrates an embodiment of a sensor head 40 of a second embodiment of a tyre tracking apparatus. A laser light source 41 (producing a scanning spot or an elongate beam) is directed towards a first faceted mirror 42. The first faceted mirror 42 is slightly inclined with respect to the axis of rotation of the tyre 2 such that light from the laser 41 can be directed across the full width of the tyre 2. A second faceted mirror 44 is similarly inclined. The mirrors 42 and 44 are further inclined with respect to each other such that light from the laser arrives obliquely at the tyre 2 when viewed in a plane normal to the axis of rotation of the tyre 2. Light specularly reflected from the surface of the tyre 2 is directed by the second mirror 44 towards a CCD camera 46. The camera is connected to a data processor 48 which analyses the reflection pattern to determine the tread depth. The data processor 48 may also identify wear resulting from over-inflation, under-inflation, or tracking errors. The data processor 48 also works out the tyre contact area in order to assess whether the tread depth is legal across the required width. The contact area may be assessed from calculations based on the tyre's dimensions, by manual entry of the tyre type or by comparison of the tread pattern with a database of tread patterns.

Figures 8 and 9 schematically illustrate an alternative lighting arrangement. As shown in figure 8, a first broad light source 50 is disposed towards one side of the tyre 2. The light source 50 may be positioned in a plane defined by the axis of rotation of the tyre 2 and a radial line to the area under inspection and the light source 50 may direct light within that plane such that light is incident at a predetermined angle, for example 45° to the surface of the tyre 2. A similarly arranged light source 52 may be provided on the opposite side of the tyre 2, as shown in figure 9.

Only one light 50, 52 is on at any given time. The raised tread pattern causes shadows 55 to be cast within the grooves 6. Thus light reflected from the tyre surface is intensity modulated with the raised tread portions reflecting more light than the shadowed portions. It will be appreciated that when a tyre 2 is new, the tread depth may exceed the width of the grooves 6. However this is irrelevant since the tyre 2 clearly has an acceptable amount of tread. As the tyre 2 wears, the depth of the grooves 6 becomes decreased and eventually they will wear down to such an extent that light can be reflected from the bottom 8 of the grooves 6. Once this occurs, the width of the shadow is directly related to the depth of the tread. The reflected light is directed towards a camera where the image is captured and sent to a data processor for processing.

Figure 10 schematically illustrates the test head of a tyre tread sensor which works in accordance with the principles herein before described with reference to figures 8 and 9. As shown in figure 10, first and second strobe lights 50, 52 are disposed either side of the tyre 2. The strobe lights 50, 52 have been drawn more displaced from the tyre 2 and would be necessary to achieve the 45° illumination illustrated in figures 8 and 9. Light reflected from the tyre 2 is collected by a faceted mirror 54 and directed towards camera 56.

Figure 11 schematically illustrates a hand held unit 90 suitable for use for performing a road side tyre check. The hand held unit 90 can utilise the line scanning mode of operation described with reference to figures 1 to 3 or the offset illumination method as described with reference to figures 8 to 10. Either technique is equally suited for this application. The sensor head is located within a housing 70 which is rotatably attached to a portion 72 incorporating a hand grip 74. The housing 70 has a slot or image window 76 formed therein, which in use, faces towards the tread of the tyre 2 under inspection. Guide rollers 78 are provided either side of the slot or image

window 76. In use, the hand-held unit 90 is arranged such that the guide rollers 78 are pressed into contact with the tyre 2 and then the hand-held unit 90 is moved around the periphery of the tyre 2. The rotary connection between the housing 70 and the further portion 72 means that the housing 70 is free to rotate such that the guide rollers 78 maintain contact with the surface of the tyre 2 and consequently such that the slot or image window 76 always faces directly towards the tread of the tyre 2. Light reflected from the tyre 2 is directed towards a photodetector, such as a camera (not shown) via a mirror 80 or other reflective elements.

A data processor (not shown) within the hand-held unit 90 analyses the reflected light pattern in order to determine whether the tyre 2 has a legal tread pattern or not. Alternatively, the data collected by the camera may be transmitted to a remote data processor, for example via a radio link. The hand-held unit 90 may be provided with an RF antenna 82 for this purpose. The hand-held unit 90 may also be provided with an LCD display 82 and an alpha-numeric keypad 84.

Figure 12 schematically illustrates an embodiment of the present invention incorporated within a rolling road 100. Rolling roads are typically used to test braking performance. The vehicle is normally positioned such that its tyres are held between two rollers 102 (only one of which is shown) which serve to allow the tyre 2 to rotate or be rotated whilst the vehicle is stationary. The light source 104 and a photodetector 106 are provided in grooves running transversely of the rolling road 100. The grooves may open towards to tyre 2 and may be protected by thick plating in order that the inspection apparatus is not damaged when vehicles drive on or off the rolling road 100. The light source 104 and photodetector 106 may be as described with respect to the earlier embodiments, and typically are separated by half a metre, although this is a design choice.

Figure 13 schematically illustrates a further embodiment in which an elongate light source 120, such as a fluorescent tube or one or more linear filament bulbs, illuminates a tyre 2 via a diffraction grating 122. This produces a broad beam of substantially parallel light 124 where the wavelength/colour varies across the beam. Light reflected from the surface of the tyre 2 is detected by a wavelength sensitive detector 126 or detector array such that the wavelength/colour of the reflected light can be analysed.

The detector 126 views a narrow portion of the tyre 2. As shown in figure 13, the region of the light beam 124 which is directed towards the detector 126 varies in accordance with the position of the reflecting surface. Thus light 128 of a first colour is directed towards the detector 126 by the surface of the tyre 2, whereas light 130 of a second colour is reflected from the bottom 8 of the grooves 6 of the tread towards the detector 128. Thus the difference in colour is indicative of the tread depth.

It is thus possible to provide a tyre inspection apparatus capable of providing quick and accurate indications of the tread depth or a pass/fail analysis of tyre condition.

The above description and accompanying drawings are only illustrative of preferred embodiments which can achieve and provide the objects, features, and advantages of the present invention. It is not intended that the invention be limited to the embodiments shown and described herein. The invention is only limited by the spirit and scope of the following claims.

Claims

1. An apparatus for measuring the depth of a tyre tread having a top surface and a bottom surface, the apparatus comprising:

   a radiation source for producing radiation for illuminating the surface of a tyre, the radiation source being positioned such that an angle of incidence of radiation emanating therefrom with respect to a tyre tread surface being measured is non-normal;
   a radiation detector responsive to radiation reflected from the tyre; and
   a processor in communication with the detector for determining the tyre tread depth by comparing differences in displacement between radiation reflected from the bottom surface of the tyre tread and radiation reflected from the top surface of the tyre tread.

2. The apparatus of claim 1, wherein the radiation source produces collimated radiation.

3. The apparatus of claim 1, wherein the radiation source produces light.

4. The apparatus of claim 1, wherein the radiation source is a laser.

5. The apparatus of claim 1, wherein the radiation source comprises an elongate light source and a collimator.

6. The apparatus of claim 1, wherein the radiation source produces a sheet of light.

7. The apparatus of claim 1, wherein the radiation source produces a light spot, and the light spot is displaced linearly across a tire tread surface being measured.

8. The apparatus of claim 7, wherein the light spot is displaced by a rotating mirror.

9. The apparatus of claim 7, wherein the light spot is

displaced by displacement of the radiation source.

10. The apparatus of claim 1, wherein the detector is a photodetector.

11. The apparatus of claim 10, wherein the photodetector is a charged coupled device.

12. The apparatus of claim 1, wherein the apparatus further comprises a reflector sized and positioned between the radiation source and a tyre tread surface.

13. The apparatus of claim 12, wherein the reflector is a faceted mirror.

14. The apparatus of claim 12, wherein the reflector is a transparent prism utilising total internal reflection.

15. An apparatus for measuring the depth of a tyre tread having a top surface and a bottom surface, the apparatus comprising:

 a radiation source for producing radiation for illuminating the surface of a tyre, the radiation source being positioned such that an angle of incidence of radiation emanating therefrom with respect to a tyre tread surface being measured is non-normal;
 a radiation detector responsive to radiation reflected from the tyre; and
 a processor in communication with the detector for determining the tyre tread depth by comparing differences in displacement between radiation reflected from the bottom surface of the tyre tread and radiation reflected from the top surface of the tyre tread;
 wherein the radiation source and the radiation detector remain in fixed positions during operation of the apparatus.

16. The apparatus of claim 15, wherein the radiation source produces collimated radiation.

17. The apparatus of claim 16, wherein the radiation source and the radiation detector are fixedly attached to a surface incorporating a rolling road.

18. An apparatus for measuring the depth of a tyre tread having a top surface and a bottom surface, the apparatus comprising:

 a radiation source for producing radiation for illuminating the surface of a tyre, the radiation source being positioned such that an angle of incidence of radiation emanating therefrom with respect to a tyre tread surface being measured is non-normal;
 a radiation detector responsive to radiation reflected from the tyre; and
 a transceiver in communication with the detector and a processor for determining the tyre tread depth by comparing differences in displacement between radiation reflected from the bottom surface of the tyre tread and radiation reflected from the top surface of the tyre tread;
 wherein the radiation source, the radiation detector and the transceiver are enclosed in a hand-held housing.

19. The apparatus of claim 18, wherein the radiation source produces collimated radiation.

20. The apparatus of claim 19, further comprising a reflector positioned between the radiation source and the radiation detector.

21. The apparatus of claim 21, wherein the hand-held housing further comprises:

 a first surface;
 a second surface rotatably attached to the first surface;
 a guide roller for following the contour of a tyre, the guide roller being rotatably attached to the first surface;
 an antenna electrically connected to the transceiver; and
 a display electrically connected to the transceiver for displaying tire tread depth information.

22. A method for measuring the depth of a tyre tread having a top surface and a bottom surface, the method comprising the steps of:

 collimating radiation;
 radiating the surface of a tyre with collimated radiation such that an angle of incidence of the collimated radiation with respect to a tyre tread surface being measured is non-normal; and
 measuring differences in displacement between radiation reflected from the bottom surface of the tyre tread and radiation reflected from the top surface of the tyre tread.

23. The method of claim 22, wherein the radiating step is performed by scanning a light spot across the tyre tread surface being measured.

24. The method of claim 23, wherein the scanning step is performed using a rotating mirror.

25. The method of claim 22, wherein the illuminating step is performed by forming a sheet of light across the tyre tread surface being measured.

26. The method of claim 25, wherein the sheet of light is reflected by a faceted mirror.

27. An apparatus for measuring the depth of a tyre tread having a top surface and a bottom surface, the apparatus comprising:

a first radiation source for producing radiation for illuminating the surface of a tyre, the radiation source being positioned such that the top surface casts a shadow over at least a portion of the bottom surface;
a radiation detector responsive to radiation reflected from the tyre; and
a processor in communication with the detector for determining the tyre tread depth by measuring the portion of the bottom surface over which the shadow has been cast.

28. The apparatus of claim 27, further comprising:

a second radiation source, the second radiation source being positioned such that the top surface casts a shadow over at least a portion of the bottom surface in a direction opposite of the shadow cast by the top surface when illuminated by the first radiation source; and
a control circuit connected to the first radiation source and the second radiation source such that the first radiation source and the second radiation source alternately illuminate the surface of the tyre.

29. A method for measuring the depth of a tyre tread having a top surface and a bottom surface, the method comprising the steps of:

illuminating the surface of a tyre such that the top surface casts a shadow over at least a portion of the bottom surface;
measuring the portion of the bottom surface over which the shadow has been cast.

30. An apparatus for measuring the depth of a tyre tread having a top surface and a bottom surface, the apparatus comprising:

a radiation source for producing a sheet of radiation with varying wavelength for illuminating the surface of a tyre, the radiation source being positioned such that radiation reflected by the top surface is of a different wavelength than radiation reflected by the bottom surface;
a radiation detector responsive to radiation reflected from the tyre; and
a processor in communication with the detector for determining the tyre tread depth by measuring the wavelength of the reflected radiation.

31. The apparatus of claim 30, wherein the radiation source includes a diffraction grating.

32. A method for measuring the depth of a tyre tread having a top surface and a bottom surface, the method comprising the steps of:

producing a collimated sheet of radiation with varying wavelength;
illuminating the surface of the tyre with the collimated sheet such that radiation reflected by the top surface is of a different wavelength than radiation reflected by the bottom surface;
measuring the wavelength of the reflected radiation.

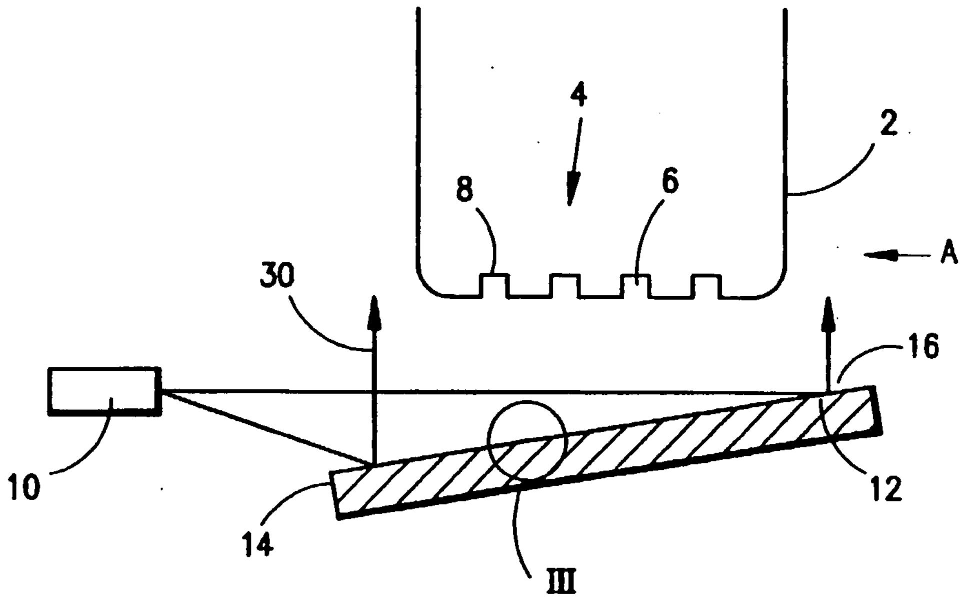


FIG. 1

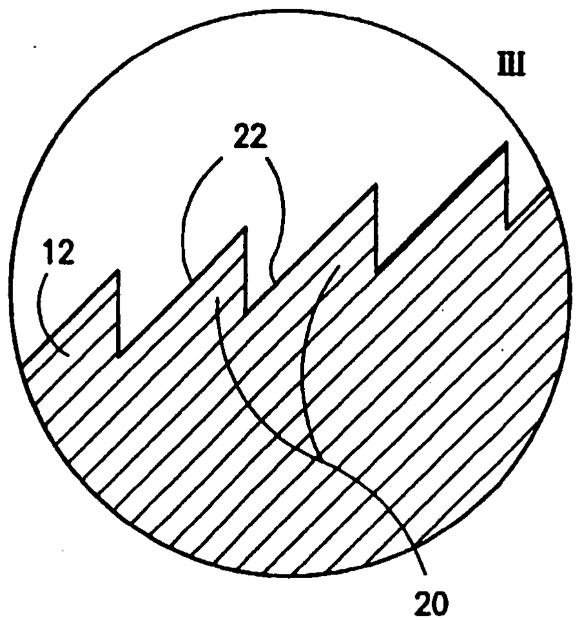


FIG. 3

FIG. 4

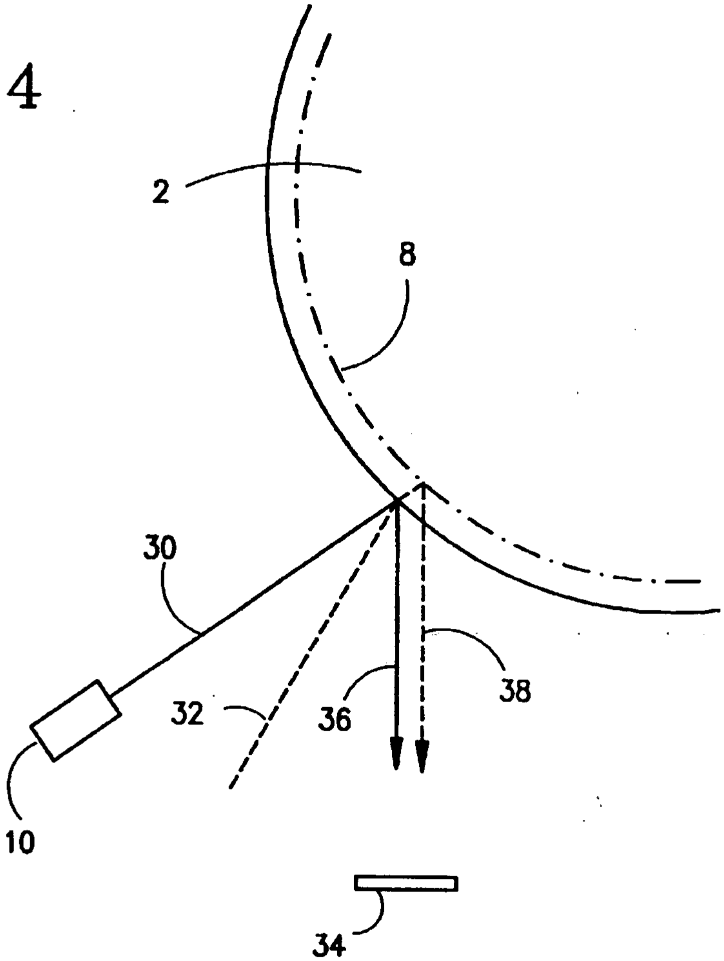
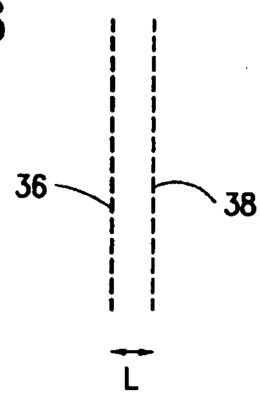


FIG. 6



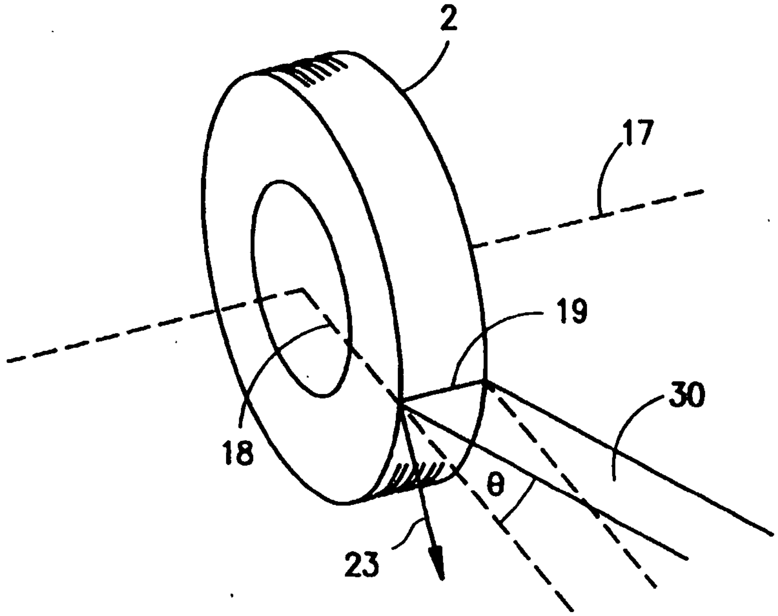


FIG. 2

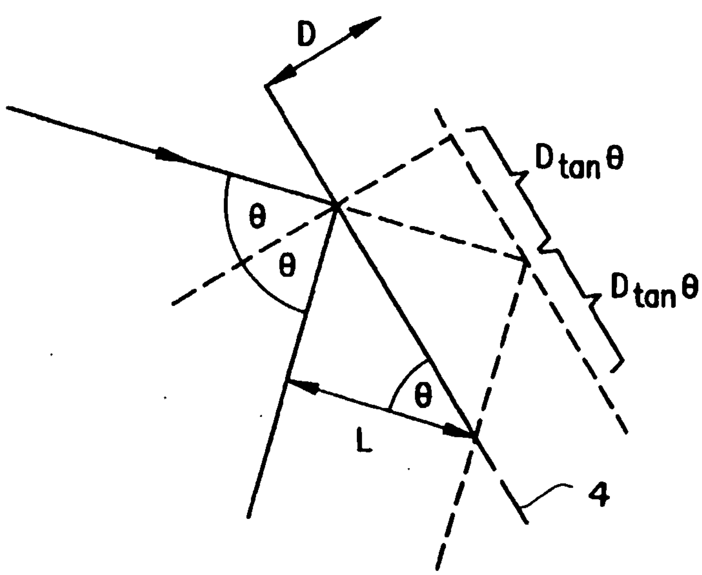


FIG. 5

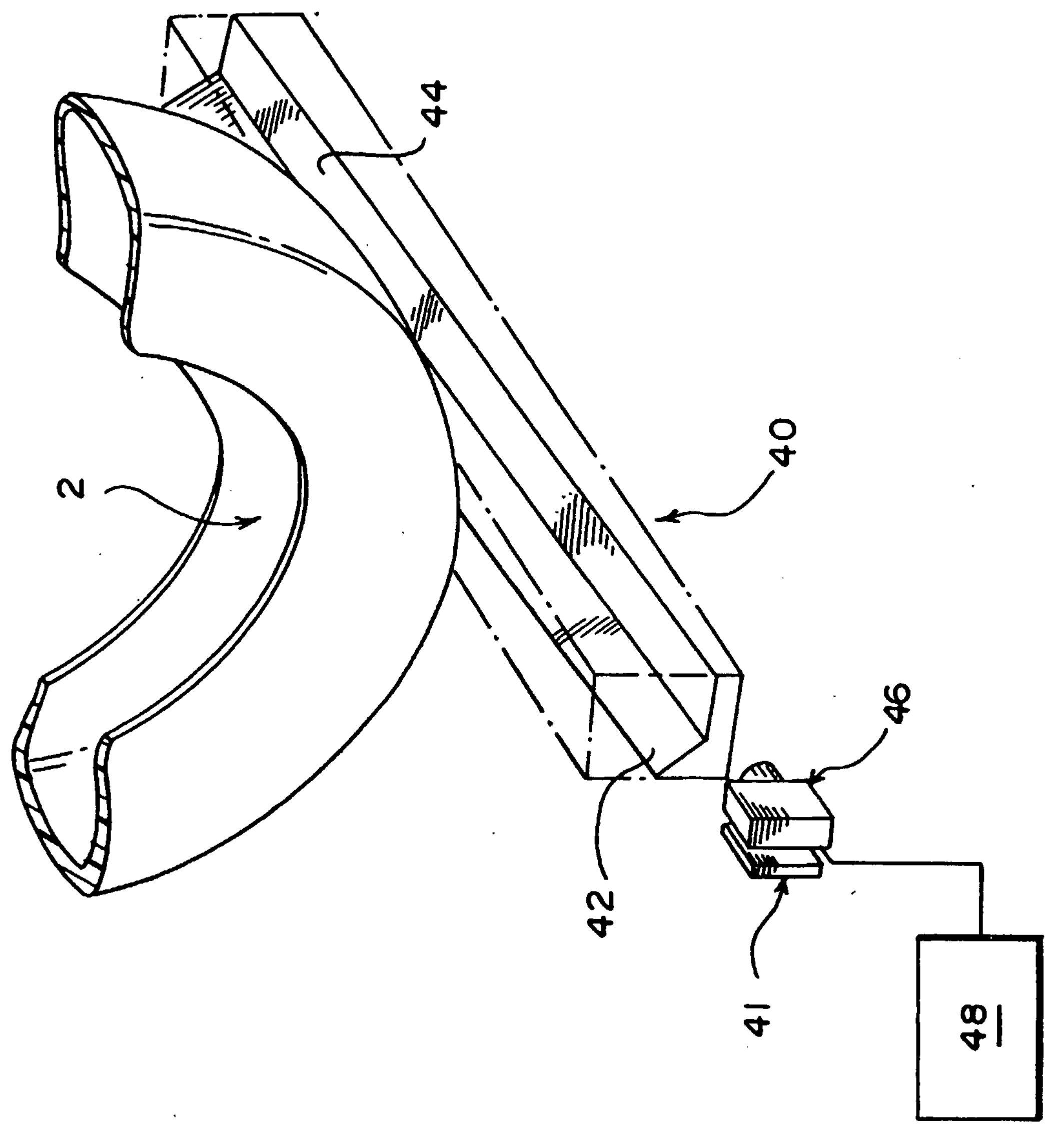


FIG. 7

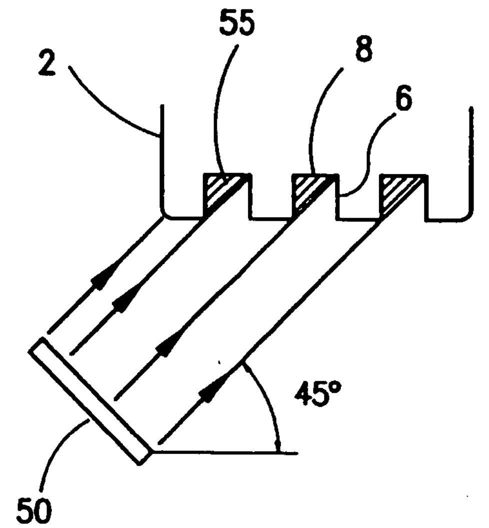


FIG. 8

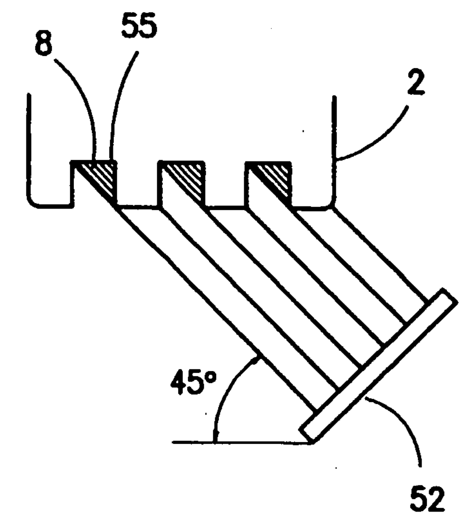


FIG. 9

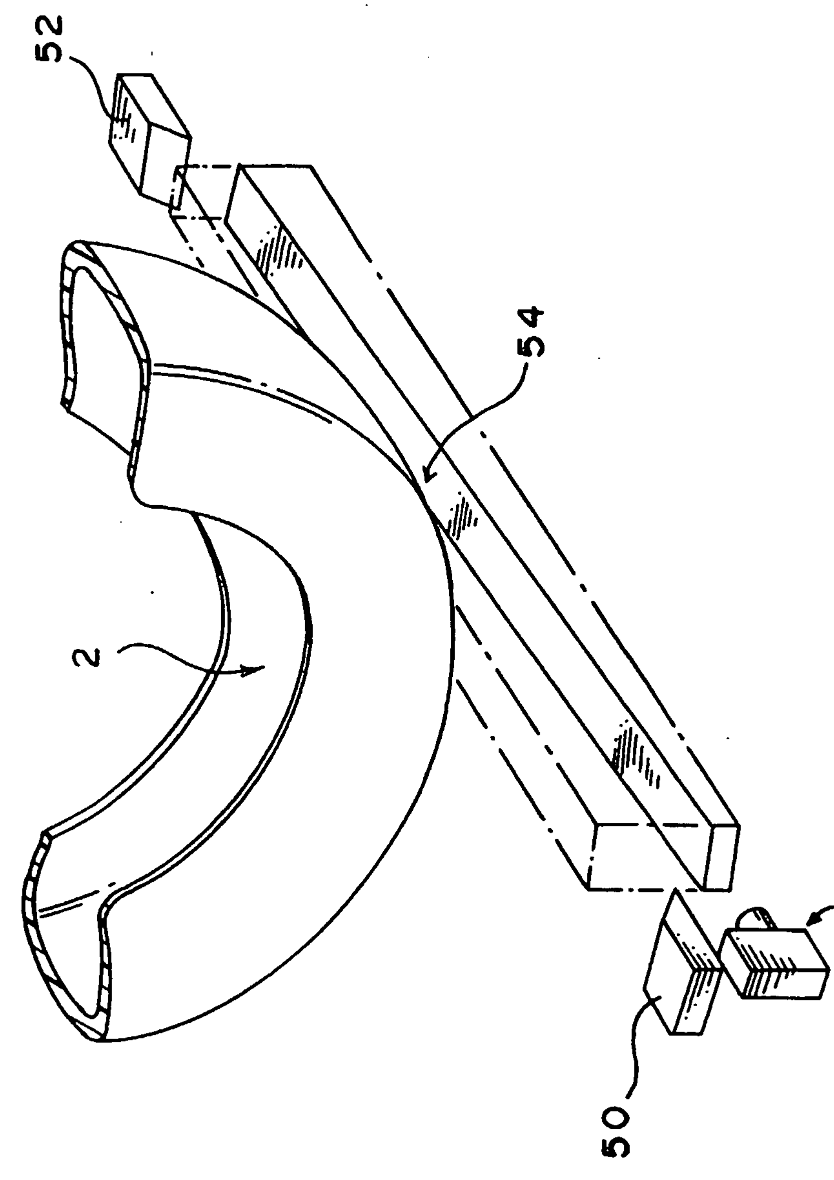


FIG. 10

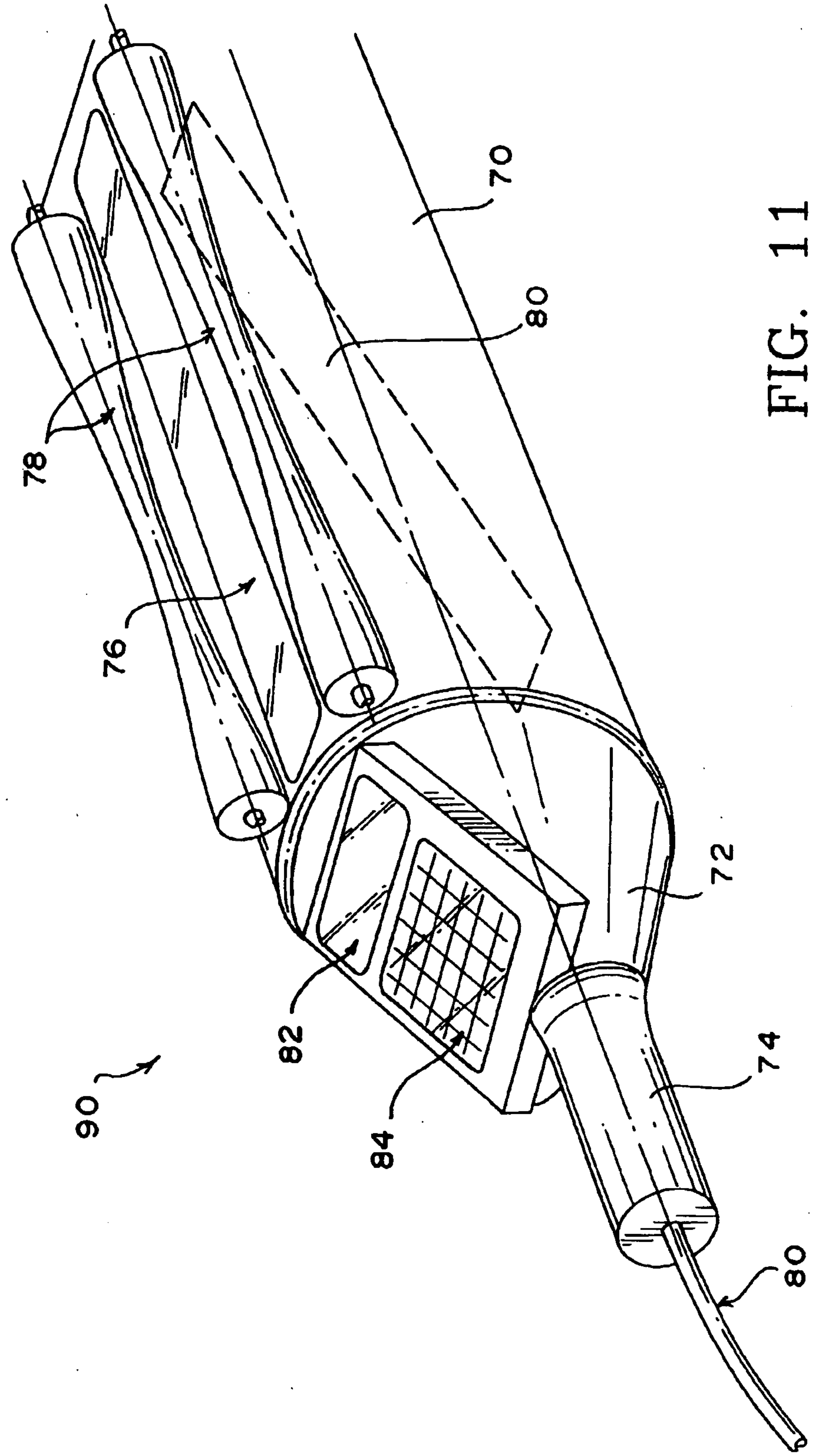


FIG. 11

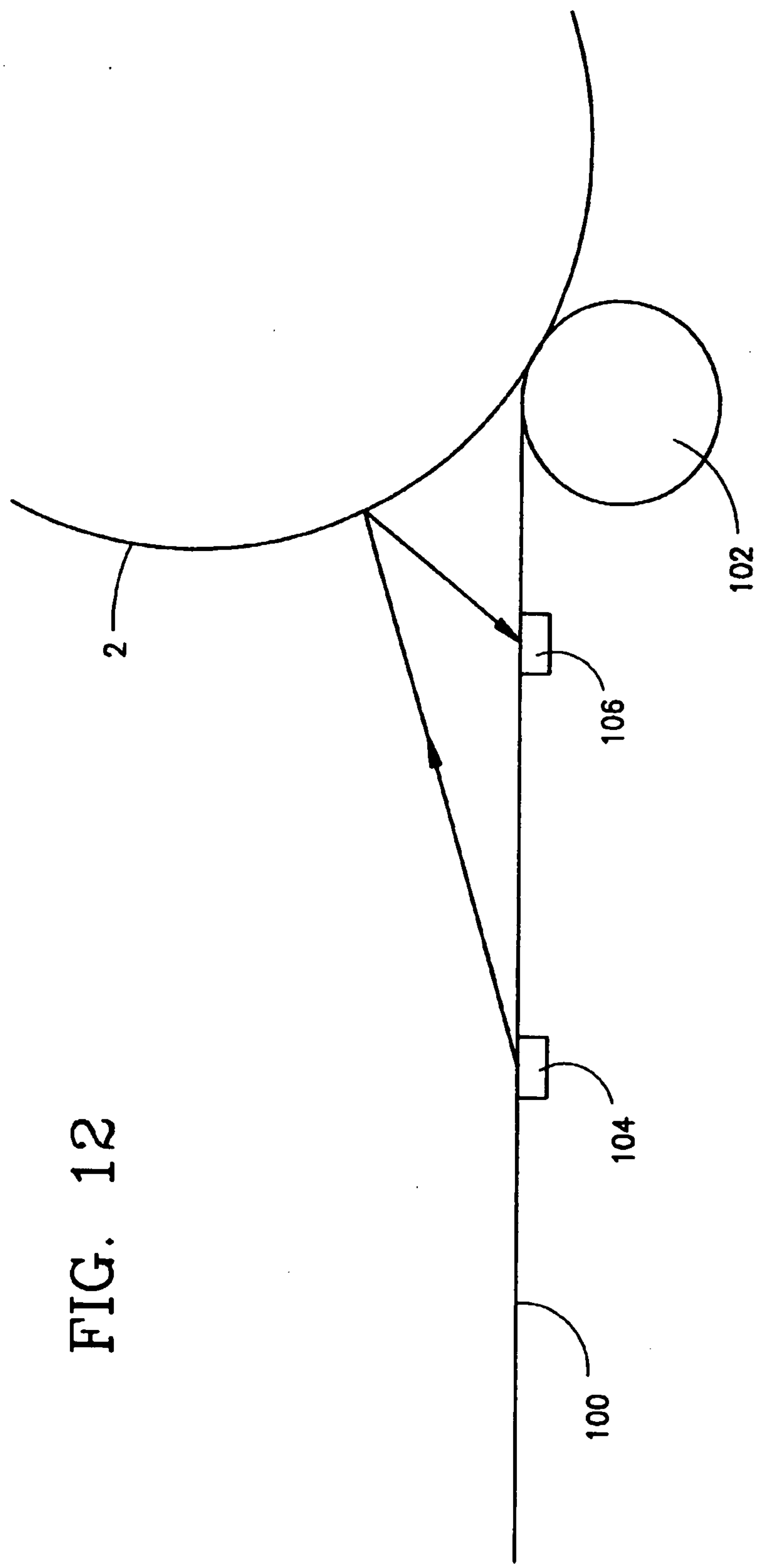


FIG. 12

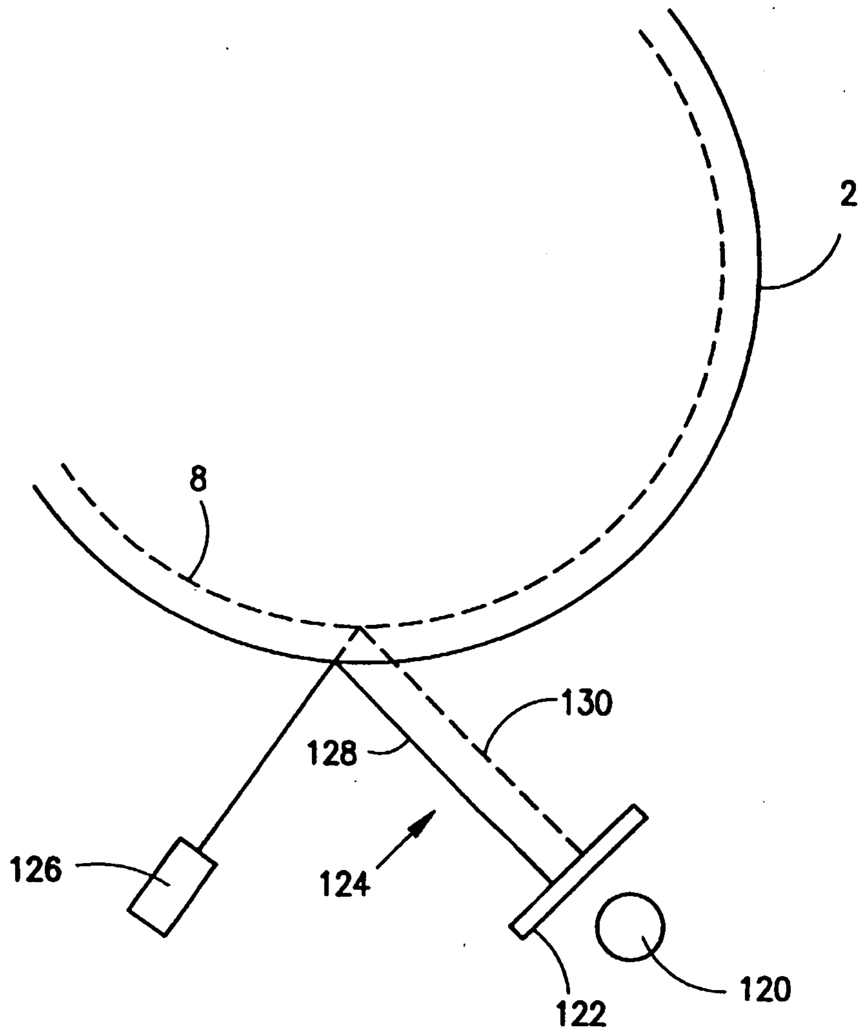


FIG. 13